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BIOLOGICAL MANIPULATION  
OF BLACKBRUSH (COLEOGYNE RAMOSISSIMA TORR.)

BY BROWSING WITH GOATS

by

Frederick D. Provenza

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

Approved:

UTAH STATE UNIVERSITY  
Logan, Utah  
1977

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Fred Provenza

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## ABSTRACT

Biological Manipulation  
of Blackbrush (Coleogyne ramosissima Torr.)  
by Browsing with Goats

by

Frederick D. Provenza, Master of Science

Utah State University, 1977

Major Professor: Dr. Philip J. Urness  
Department: Range Science

The purpose of this study was to provide data on responses of Angora goats and blackbrush (Coleogyne ramosissima) to a biological manipulation program. Blackbrush utilization levels averaged 30, 16, and 6 percent (545, 367, and 147 kg per hectare) for the heavily, moderately, and lightly browsed pastures, respectively; removal rates of 77, 38, and 19 percent (1164, 582, and 291 kg per hectare) were projected.

Statistically significant differences in body weight loss ( $P=0.052$ ) were noted for goats browsing in different replications. Goats lost an average of 14 and 19 percent of body weight in replications one and two, respectively. Differential weight loss appeared to be related to variable crude protein levels in blackbrush twigs.

Small, but statistically significant differences were noted between replications for crude protein ( $P=0.002$ ) and phosphorus ( $P=0.019$ ) content in blackbrush twigs. Crude protein content averaged 4.9 and 4.4 percent for replications one and two,

respectively; phosphorus content averaged 0.18 and 0.15 percent for replications one and two, respectively.

No statistically significant differences in plant production were noted among stocking rates; this was primarily a result of the low utilization levels. Site (replications) affected plant response ( $P=0.135$ ), and terminal branches produced more current season's growth than did basal branches ( $P=0.162$ ).

(77 pages)

## INTRODUCTION

### Significance and Statement of Problem

Blackbrush (Coleogyne ramosissima Torr.) occurs on millions of hectares of rangeland in the southwestern United States, yet little information is available on this plant for guiding management decisions. Bowns (1973) and Bowns and West (1976) have published the most comprehensive review of literature on blackbrush. They emphasized the lack of information and suggested, as one area for future research, the determination of methods for removing woody plant material to stimulate the production of more palatable basal and axillary shoots.

The terminal branches of blackbrush tend to die back several centimeters from the tip resulting in a spinescent growth form (Bowns 1973). Death of terminal branches suppresses apical dominance which allows lateral branch development. This development of lateral branches has a pronounced effect on compacting the plants. As a result of the compacted, spinescent growth form, the accessibility and palatability of blackbrush twigs is low for most ungulates.

Removal of spinescent material from blackbrush plants stimulates sprouting from basal and axillary buds. Bowns (1973) indicated that plants heavily hedged by livestock produced new growth which was more accessible, more palatable, and possibly more nutritious than more woody portions. Analyses by Reynolds and Sampson (1943) showed that the nutritive value of regrowth



plant material in chaparral species was higher than that of unbrowsed plant material. Bowns and West (1976) reported that simulated brush-beating treatments produced resprouting that ranged from "excellent to fair" in 67 percent of the plants treated. However, energy-intensive mechanical treatments, such as chaining or beating, are expensive and sometimes have adverse environmental impacts.

Domestic goats have been used to economic and ecological advantage as biological manipulators of woody vegetation in some areas of the West (King 1956, Magee 1957, Davis et al. 1975). The potential of the goat for such purposes can be viewed from several aspects. Firstly, land managers are interested in biological techniques for manipulating vegetation. With mounting concerns for environmental protection, traditional range improvement tools such as chemical herbicides, chaining, plowing, and burning are receiving close scrutiny. Controlled browsing, however, can often accomplish comparable goals with fewer environmental risks.

Secondly, some authorities (Martin 1970, Box 1974) believe that for rangelands to contribute fully toward supplying mankind's future needs for animal protein, unconventional kinds of animals will be needed. The shrub component of rangelands represents a food niche that is largely unoccupied by our present mix of domestic animals. The goat is a strong candidate for filling this niche in many areas, but the specifics for managing the animal are poorly understood.

Finally, with encroachment by an expanding human population,



common use of rangelands by species whose food habits complement each other will be increasingly important. With its preference for woody vegetation, the goat has the potential for complementing species such as cattle and sheep that prefer herbaceous vegetation (Wilson 1969). Also, goats have a high threshold for bitter tastes which permits them to choose from a wider range of plant species than many ungulates (Bell 1959).

#### Purpose and Objectives

Jenson et al. (1960) set the stocking rate of blackbrush range in southern Nevada at 12 to 24 hectares per animal unit month, yet total "available" blackbrush forage in southwestern Utah has been estimated at 1513 kg per hectare.<sup>1</sup> This apparent discrepancy is partially a result of the compacted, spinescent growth form which reduces accessibility and palatability of blackbrush twigs for cattle. The purpose of this research was to provide data on responses of Angora goats and blackbrush to a biological manipulation program intended to increase range carrying capacity for cattle.

To quantify plant and animal interrelationships, the following objectives were proposed:

1. To determine the effects of three levels of stocking with Angora goats (649, 325, and 162 goat days per hectare) upon the degree of utilization of blackbrush.
2. To determine the body weight response of Angora goats

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<sup>1</sup>Unpublished Soil Conservation Service data

browsing blackbrush at three stocking levels (649, 325, and 162 goat days per hectare).

3. To determine the crude protein and phosphorus content of blackbrush from samples collected at one week intervals during the browsing period.
4. To assess the relationship between utilization levels (649, 325, 162, and 0 goat days per hectare) and the subsequent growing season's production of twig growth by blackbrush.

## REVIEW OF LITERATURE

Blackbrush, a densely branched shrub up to two meters tall, occupies extensive areas in southern Nevada, southeastern California, northern Arizona, southwestern Colorado, and southern Utah (Figure 1). In southern Utah, blackbrush occupies more than one million hectares (Kuchler 1964).

Where blackbrush cover is high, it forms essentially pure stands (Humphrey 1953, Bowns 1973), and the cover value (37 to 51 percent) is consistently the highest of the vegetation occurring in the transition area between the Mojave and Great Basin deserts (Beatley 1975). Bowns and West (1976) indicated that the greatest economic use of blackbrush-dominated ranges in Utah was winter browsing by mule deer and desert bighorn sheep, and winter and spring livestock browsing.

Blackbrush is generally considered a poor forage species. Humphrey (1953, 1955) considered it poor forage during spring, summer, and fall for cattle, but fair forage for goats during these seasons. During the winter when other feed was scarce, he rated blackbrush as fair forage for cattle. Sampson and Jespersen (1963) rated the shrub as good to poor forage for goats and poor forage for cattle on California ranges. The U.S. Forest Service (1937) viewed blackbrush as fair forage for cattle during the winter on southern Utah ranges. Bowns and West (1976) stated that blackbrush in southern Utah provided fair winter and spring forage for sheep and cattle. Work by



Figure 1. Map of blackbrush distribution according to Bowns and West (1976).

Bradley (1965) and Wilson (1967), however, indicated the importance of the species for desert bighorn sheep. Additionally, Leach (1956) found it to be an important contributor to the winter diet of mule deer.

Nutritionally, blackbrush is reputed to be low in crude protein and phosphorus. Average crude protein levels cited by Bowns and West (1976) for material harvested in May, August, November, and February were 7.7 percent for leaves and 3.7 percent for stems. Phosphorus content averaged 0.12 percent for leaves and 0.11 percent for stems. Crude protein and phosphorus concentrations were highest in the leaves at the May collection averaging 8.8 percent and 0.14 percent, respectively. Huston et al. (1971) recommended a minimum of 9.0 percent crude protein and 0.16 percent phosphorus in the diet of Angora goat wethers and dry does for a medium level of production; requirements for pregnant and lactating does, developing billies, kids, and yearlings are higher. Cook and Harris (1968) recommended a diet containing 4.4 percent digestible protein and 0.17 percent phosphorus for cattle and sheep during gestation, with requirements for lactation higher.

Physiologically, blackbrush appears to be tolerant of heavy twig removal but intolerant of fire. Jenson et al. (1960) indicated that burning effectively destroyed blackbrush, but plant succession was variable on different sites and replacement shrubs were usually undesirable forage species, such as snakeweed (Gutierrezia microcephala). Widescale burning for this vegetation type was not recommended by Bowns and West (1976).



Published research on the use of goats to alter plant growth form is limited. Most work has been directed toward control of undesirable species, rather than alteration of plant morphology. Domestic goats have been used successfully as biological controllers of oak woodlands in Texas (King 1956, Magee 1957, Norris 1968) and Colorado (Davis et al. 1975), and of Acacia-dominated ranges in South Africa (DeToit 1973).

The literature indicated that goats eat more browse than forbs and grasses, and Wilson (1969) concluded from a review of the literature that goats eat more browse than sheep or cattle. Fraps and Cory (1940) stated that browse constituted more than 50 percent of the goat's diet but that goats utilized a wide variety of forage species. French (1970) reported diverse plant species and forage types in the goat's diet. Huss (1972) stated that the ideal goat diet does not consist solely of browse, but that browse was possibly the major portion of feed consumed.

Maher (1945) indicated that goat's ability to consume browse is due to its mouth which has a mobile upper lip and a prehensile tongue. These permit the goat to eat browse not normally eaten by other livestock, and make the goat a good candidate for blackbrush manipulation. Observations from the Navajo Indian Reservation indicated that goats browse blackbrush heavily (U.S. Forest Service 1937), thus providing the hedging conducive to stimulation of basal and axillary twig growth. Davis et al. (1975) and Merrill and Taylor (1976) indicated that the effective browsing height of goats was over two meters;

thus, all of the blackbrush canopy (average height one meter) was within the reach of goats.

## STUDY AREA

The experiment was conducted on Bureau of Land Management administered land in the extreme southwestern corner of Utah near the town of Gunlock, located at  $37.5^{\circ}$  north latitude and  $114^{\circ}$  west longitude. The site was within the area studied by Bowns (1973) and Bowns and West (1976) in their autecological investigations of blackbrush, and was considered representative of the blackbrush type. The reader is referred to these publications for a detailed description of vegetation, soils, and climate of the area.

The study area was at an elevation of 1280 m and consisted floristically of blackbrush associated with juniper (Juniperus osteosperma) (Figure 2). The soil series of the site was a Pastura Loam with an A-C horizon sequence underlaid by a petrocalcic (caliche) horizon (Bowns 1973). A Bureau of Land Management rain gauge at Tobin Wash, which was in close proximity to the study site, showed 272 mm average annual precipitation during the period 1966 to 1977. A total of 227 mm precipitation fell during the year of this study.

The physical design of the experiment consisted of two blocks of 8 hectares each. Within each block, the control pasture was 1 hectare, the heavily stocked pasture was 1 hectare, the moderately stocked pasture was 2 hectares, and the lightly stocked pasture was 4 hectares (Figure 3). These areas were enclosed by a 1.2 m net wire fence supported by steel posts.





Figure 2. View of the study site showing the blackbrush understory and the juniper overstory.

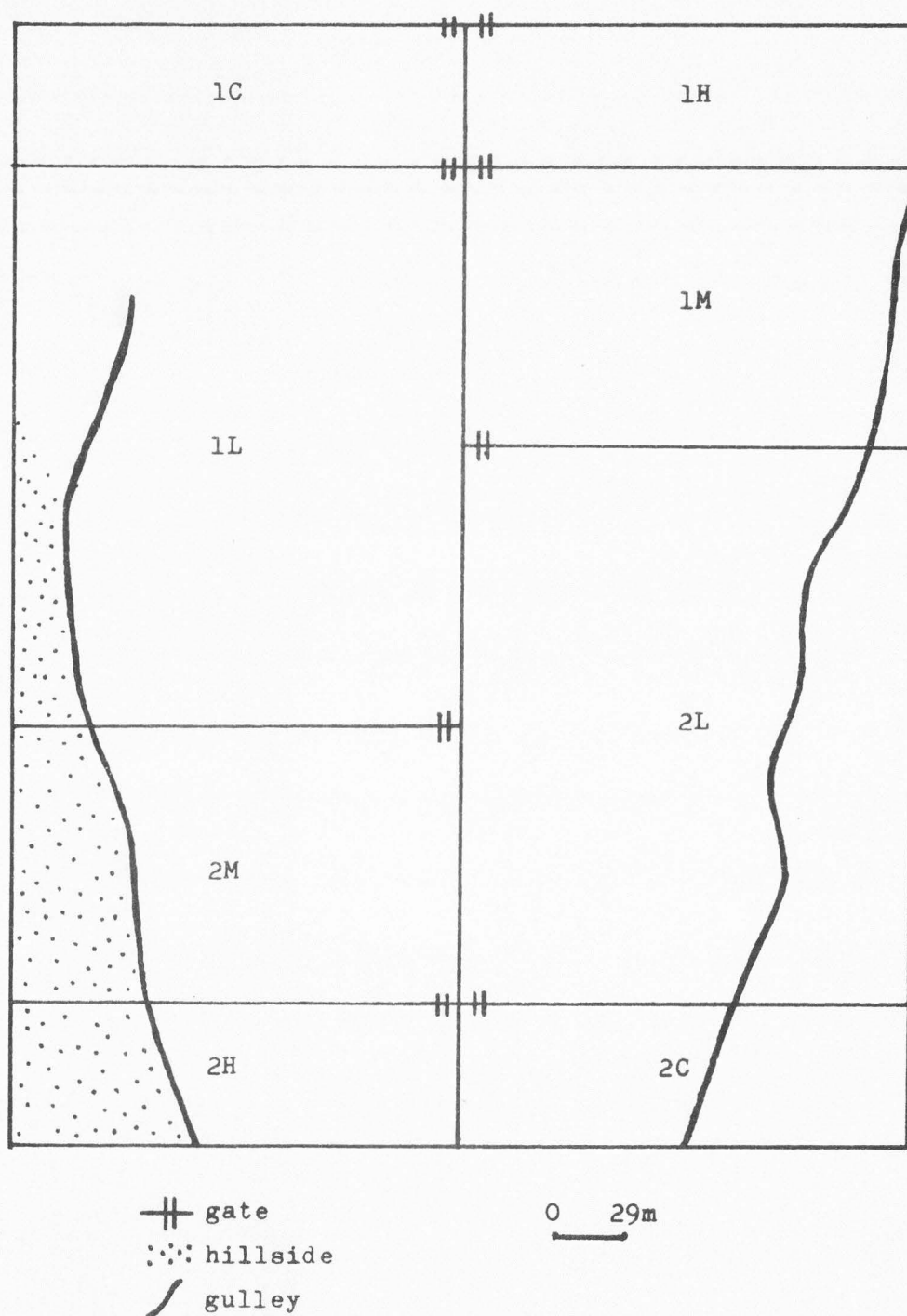


Figure 3. Pasture layout for the blackbrush study site. A prefix of 1 or 2 indicates the replicate, and a suffix of H, M, L, or C indicates a stocking rate of heavy, moderate, light, or control, respectively.

Eleven Angora goats, primarily does and yearlings, were introduced into each pasture the first week in January and remained 59 days.

A sampling intensity of 50 plants per hectare was employed in a restricted random sample. Five transects were systematically established in each of the 1- and 2-hectare pastures; 10 plants were randomly selected along each transect in the 1-hectare pastures, and 20 plants were randomly selected along each transect in the 2-hectare pastures. Ten transects were systematically established in each of the 4-hectare pastures, and 20 plants were randomly selected along each transect.

The statistical design of the experiment was a simple factorial arranged in randomized blocks. There were four rates of stocking (649, 325, 162, and 0 goat days per hectare) and the experiment was replicated twice. Results were considered statistically significant at  $\alpha \leq .10$  unless otherwise stated in this paper.

## METHODS

### Quantifying Utilization

Assessments of browse utilization provide a basis for big game range management and have received much attention in the wildlife literature. Methods used to obtain this information vary from measuring marked twigs before and after browsing (Dasmann 1948, Smith and Urness 1962), to regression approaches for determining browsed twig length and weight from twig diameter (Basile and Hutchings 1966, Telfer 1969, Lyon 1970), to estimating overall percentage utilization (Aldous 1944, Cole 1958).

Extensive methods of estimating utilization generally require less time than other methods, but lack the accuracy necessary for intensive range management. Conversely, before-and-after measurements provide reliable utilization estimates, but measuring is tedious and requires large time expenditures. Regression techniques, however, can provide reliable estimates of utilization with moderate time expenditures.

Goat utilization was quantified by three methods:

1. Length measurements of tagged branches before and after goat browsing.
2. A regression approach for determining twig length removed by goats, after the browsing period.
3. Determination of the kilograms of blackbrush browsed per hectare by goats.

The accuracy of the regression approach was compared to the accuracy of the before-and-after approach, and percent utilization values obtained from these approaches were related, by regression analysis, to kilograms of blackbrush browsed by goats per hectare.

#### Before-and-after approach

Percent utilization was quantified by length measurements of marked branches on sample plants (one branch per plant) before and after goat browsing. The before measurement was made in December and included twigs containing wood that was one-half or more years old. The after measurement was made in March.

Sample plants were marked with consecutively-numbered metal tags attached to a branch near ground level with a wire (Figure 4). A point on each branch was marked with a copper wire and a dot of red ink (Figure 4); twig length, from the marked point to the end of the branch, was measured before and after browsing. Approximately 100 cm of twig material were measured on each branch before browsing. If browsing removed the twig below the marked point, utilization was considered 100 percent. Utilization was computed as follows:

$$U = \frac{B - A}{B} (100)$$

where U = percent utilization  
 B = length before browsing  
 A = length after browsing





Figure 4. View of a sample plant showing metal tag and marked branch.

### Regression approach

Regression equations relating twig length and oven-dry twig weight to air-dry twig diameter were established by sampling 40 twigs in each pasture. Twigs selected for measurement corresponded in size and growth form to those browsed by goats; goats did not strip leaves and bark from blackbrush branches. Basal diameters of browsed twigs ranged from 1 to 5 mm, and 10 twigs were sampled in each of four basal diameter classes (1.0 - 1.9 mm, 2.0 - 2.9 mm, 3.0 - 3.9 mm, 4.0 - 5.0 mm) in each pasture. Basal diameter, as used in this paper, refers to the diameter at the end of the remaining branch from which a twig was removed. The end of the remaining branch was clipped 3 cm below the point where the sample twig was clipped, and air-dried for two weeks before the diameter was measured with calipers to the nearest 0.05 mm. Because branches were observed to shrink slightly at the browsing point upon air-drying, samples were allowed to air-dry before measurement. Twigs were oven-dried for 24 hours at 100° C, weighed to the nearest 0.01 gm, and measured to the nearest 1.0 mm.

Regression equations relating twig length and air-dry twig diameter, and oven-dry twig weight and air-dry twig diameter were established for each pasture. Intercepts and slopes of regression lines for each pasture were compared to determine if the data from all pastures could be pooled.

After goat browsing in March, caliper measurements were made on each twig marked for the before-and-after approach (Figure 5). Measurements were made at the marked point (copper wire and red ink dot) and at each browsed tip distal

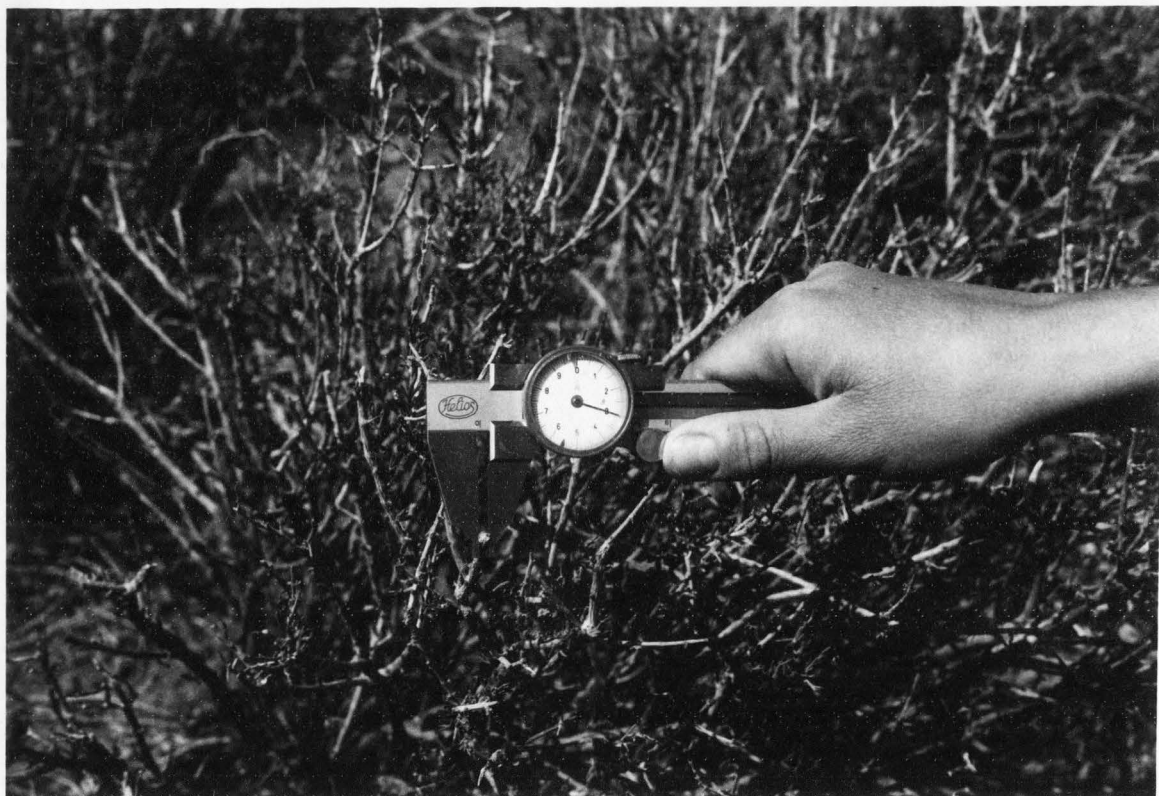


Figure 5. View of calipers being used to measure twig diameter.



to this point. If browsing removed the twig below the marked point, utilization was considered 100 percent. Utilization was computed as follows:

$$U = \frac{\Sigma PB}{PT} (100)$$

where U = percent utilization

PT = predicted twig length

$\Sigma PB$  = sum of the predicted browsed  
twig lengths

#### Determining weight removed

To determine the kilograms of blackbrush browsed by goats at the three stocking rates, the following information was necessary:

1. The number of blackbrush plants in each pasture.
2. The average number of browsed twigs per blackbrush plant in each pasture.
3. The average weight of a browsed blackbrush twig in each pasture.

The number of blackbrush plants per unit area (density) was determined by sampling randomly selected 100 m<sup>2</sup> plots within each pasture. Four plots were sampled in each 1-hectare pasture, 8 plots were sampled in each 2-hectare pasture, and 16 plots were sampled in each 4-hectare pasture. The average number of plants per plot in each pasture was multiplied by the number of 100 m<sup>2</sup> units in each pasture to obtain an estimate of the total number of plants in the pasture. To supplement density data, the mean area occupied by plants in each pasture was estimated by dividing the plot size (100 m<sup>2</sup>) by the average number of plants per plot. Also, the volume of each sample

plant was determined by the formula:

$$V = \frac{\pi ab}{4} (h)$$

where V = volume

a = crown diameter at the widest point

b = crown diameter perpendicular to bisect "a"

h = crown height

Measurements were read to the nearest 1 cm, and the volume of the enclosed cylindroid was calculated to the nearest  $0.01 \text{ m}^3$ .

The average number of browsed twigs per plant in each pasture was obtained by counting all browsed twigs on each sample plant. Ten percent of the browsed twigs on each sample plant were systematically selected and measured with calipers to the nearest 0.05 mm to obtain a sample of browsed twig diameters for each pasture (Figure 5).

The weight-diameter regression equation (p. 17) was used to convert air-dry diameters to oven-dry weights for twigs removed by browsing. The following formulae were used to derive kilograms of blackbrush browsed per hectare by goats:

$$1) \quad MWP = MWTP \times MBTP$$

$$2) \quad KH = \frac{MWP \times PP}{HP}$$

where MWP = mean weight of browse removed per plant in pasture X

MWTP = mean weight of a browsed twig in pasture X

MBTP = mean number of browsed twigs per sample plant in pasture X

KH = kilograms of browse removed per hectare in pasture X

PP = number of plants in pasture X

HP = number of hectares in pasture X

### Quantifying Body Weight Response

To determine the body weight response of goats during the period they were browsing blackbrush, each goat was tagged and weighed at the onset of browsing in January and weighed at the termination of browsing in March. During the browsing period, goats had free access to trace mineral blocks and water. To obtain baseline information on weight response for guiding future research, goats were not given a protein-phosphorus supplement.

### Quantifying Crude Protein and Phosphorus Content

Hand-plucked browse samples, simulating material consumed by goats as closely as possible, were collected from each pasture at one-week intervals during the browsing period. These samples were air-dried and ground through a Wiley mill with a 40-mesh per centimeter screen. A 1-gm sample was analyzed for each pasture on each collection date. Crude protein content was determined by the Kjeldahl method (Horwitz 1970), and phosphorus content was determined by the ammonium molybdate-ammonium vanadate method described by Chapman and Pratt (1961).

### Quantifying Plant Response

Seasonal growth on two branches from each sample plant was measured in September, after blackbrush growth had ceased (Bown 1973). A terminal branch was selected from the outer

edge of the plant canopy, and a basal branch was selected from branches arising nearer the base of the plant within the terminal branch canopy. Random selection of both branches was assured by placing a circular hoop, 0.9 m in diameter and covered with a 5-cm wire grid, over each plant (Figure 6). The grid was supported by a metal stake which allowed the grid to revolve; the stake was positioned in the center of each sample plant and the grid was spun and allowed to come to rest. Two metal pins were inserted at randomly assigned points on the grid intersections, and the current season's growth on the terminal or basal branch nearest a pin was measured to the nearest 1.0 mm.



Figure 6. Grid used to determine the branches on which current season's growth was measured.



## RESULTS AND DISCUSSION

Quantifying UtilizationBefore-and-after approach

Table 1 presents the percentage of blackbrush utilized by goats based on the before-and-after approach and Table 2

Table 1. Percent blackbrush utilization (mean  $\pm$  95 percent confidence limits) by Angora goats browsing at three stocking rates.

Pasture <sup>1</sup>	Stocking rate <sup>2</sup>	Before-and-after estimates	Regression estimates
1H	649	30 $\pm$ 10	31 $\pm$ 11
2H	649	31 $\pm$ 12	34 $\pm$ 12
1M	325	13 $\pm$ 6	15 $\pm$ 6
2M	325	19 $\pm$ 7	21 $\pm$ 7
1L	162	8 $\pm$ 3	8 $\pm$ 3
2L	162	4 $\pm$ 2	4 $\pm$ 2

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

<sup>2</sup>Goat days per hectare

presents the analysis of variance for utilization differences at the three stocking rates. This analysis indicates significant differences in blackbrush removal at the three stocking rates.

Based on the assumption that 6 goats are equivalent to one animal unit (Heady 1975), the projected removal rates for the heavily, moderately, and lightly stocked pastures were 77, 38, and 19 percent, respectively; it is evident that the percent

Table 2. Analysis of variance for utilization differences based on the before-and-after approach.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	699	803.25		
Stocking rates	2	25,740.32	22.55	P=0.042
Replications	1	7.61	<1	NS
Error	2	1,141.55		
Sampling	694	731.56		

of blackbrush consumed by goats was low. This was primarily a result of the great quantity of blackbrush, the small size of the goats, and the relatively low number of goats per pasture, considering that goats ate blackbrush readily (Figure 7). The use of larger, older animals (e.g. two-year-old wethers) would probably increase utilization. Supplementation might also increase utilization. Huston et al. (1971) indicated that pregnant Angora does fed diets adequate in protein and energy consumed 0.45 kg more dry-matter per day than did does fed diets deficient in these nutrients. Moir and Harris (1962) showed that both dry matter intake and the intake rate of sheep were increased when nitrogen intake increased above 0.74 percent (4.6 percent crude protein).

#### Regression approach

Regression equations providing the best description of the data included in the sample are of the general form:



Figure 7. Angora goats browsing blackbrush plants.



- 1) natural logarithm length =  $B_0 + B_1(\text{natural logarithm diameter})$
- 2) natural logarithm weight =  $B_0 + B_1(\text{natural logarithm diameter})$

" $B_0$ " and " $B_1$ " are constants for blackbrush. Diameters must be converted to natural logarithmic values before use in these equations. The values obtained are also natural logarithms; the antilog will provide the length or oven-dry weight corresponding to the diameter used in the equation.

Lines produced by regressing twig lengths on air-dry twig diameters for each pasture are presented in Figure 8. These lines were obtained by using indicator variables as explained by Neter and Wasserman (1974, pp. 297-338). Table 3 presents the estimated regression coefficients and F ratios for each pasture.

Each F ratio in Table 3 indicates the addition of the regression coefficient to the model, given previous regression coefficients in the model. After the intercept for pasture 2L ( $B_1$ ) and the slope for pasture 2L ( $B_1$ ) were in the model, only the slope for pasture 2H ( $B_{10}$ ) added significantly to the model. No other intercept ( $B_2$  through  $B_6$ ) or slope ( $B_7$  through  $B_{11}$ , excluding  $B_{10}$ ) variables added significantly to the model. The slope for pasture 2H, although a statistically significant addition to the model, was not considered practically important due to the small magnitude of the estimated regression coefficient (-0.227).

Lines for the various pastures were obtained from the estimated regression coefficients for pasture 2L. For example, the intercept for pasture 1L was obtained by adding  $B_0$  and

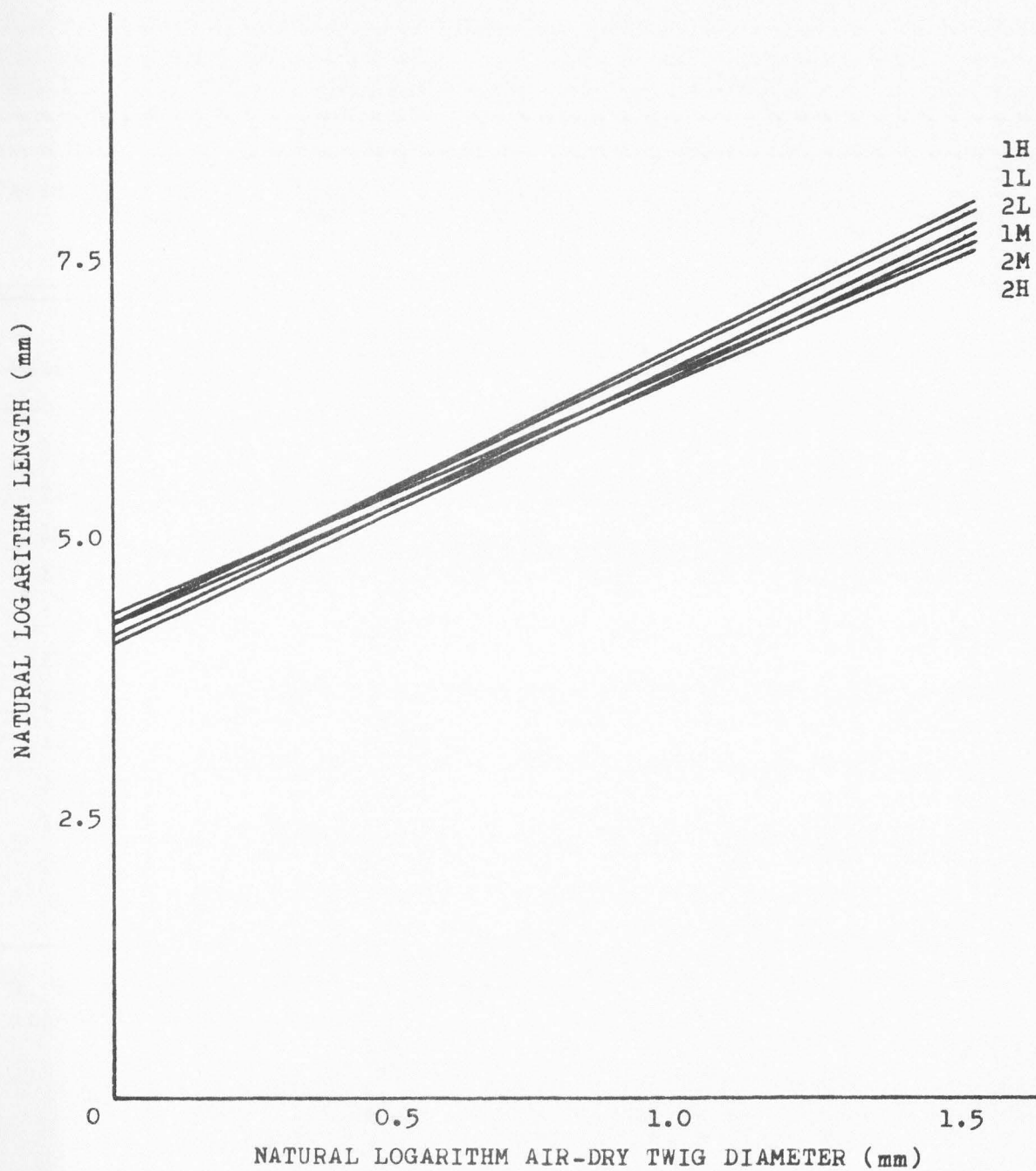


Figure 8. Relationship of twig length to air-dry twig diameter for blackbrush shrubs in six pastures.

Table 3. Estimated regression coefficients for six pastures in which twig length was regressed on air-dry twig diameter.

Pasture <sup>1</sup>	Regression coefficient	Estimated regression coefficient	F ratio	Significance
2L	B <sub>0</sub>	4.026		
2L	B <sub>1</sub>	2.399	1549.97	P<0.000
1H	B <sub>2</sub>	0.109	0.61	NS
1M	B <sub>3</sub>	-0.039	0.07	NS
1L	B <sub>4</sub>	0.136	0.95	NS
2H	B <sub>5</sub>	0.160	1.49	NS
2M	B <sub>6</sub>	0.229	2.30	NS
1H	B <sub>7</sub>	0.061	0.21	NS
1M	B <sub>8</sub>	0.001	0.00	NS
1L	B <sub>9</sub>	0.033	0.06	NS
2H	B <sub>10</sub>	-0.227	3.24	P=0.073
2M	B <sub>11</sub>	-0.223	2.50	NS

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

$B_4$  ( $4.026 + 0.136$ ), and the slope for pasture 1L was obtained by adding  $B_1$  and  $B_9$  ( $2.399 + 0.033$ ).

Fitting a model with indicator variables produced the same results as fitting separate equations for each pasture. An advantage of using indicator variables was that one run on the computer yielded all six regression equations. Also, tests for comparing the slopes and intercepts of the pastures were seen as tests of regression coefficients in a general linear model (Neter and Wasserman 1974).

Since slope variation for pasture 2H was not considered important, data from all six pastures were pooled to better estimate the regression parameters (Figure 9). The regression equation is:

$$\text{natural logarithm length} = 4.0398 + 2.3855(\text{natural logarithm diameter})$$

Regression was selected as an alternative method to before-and-after measurements for estimating utilization because the regression approach reduces man-hour costs. Of interest, however, is how the regression approach compares to the before-and-after method in accuracy. Regression estimates of the percentage of blackbrush removed by goat browsing are presented in Table 1. These estimates are all within 3 percent of the values obtained by the before-and-after procedure. The analysis of variance for utilization differences at the three stocking rates based on the regression approach is presented in Table 4. This analysis indicates significant differences in blackbrush removal at the three stocking rates. These differences occur at a somewhat

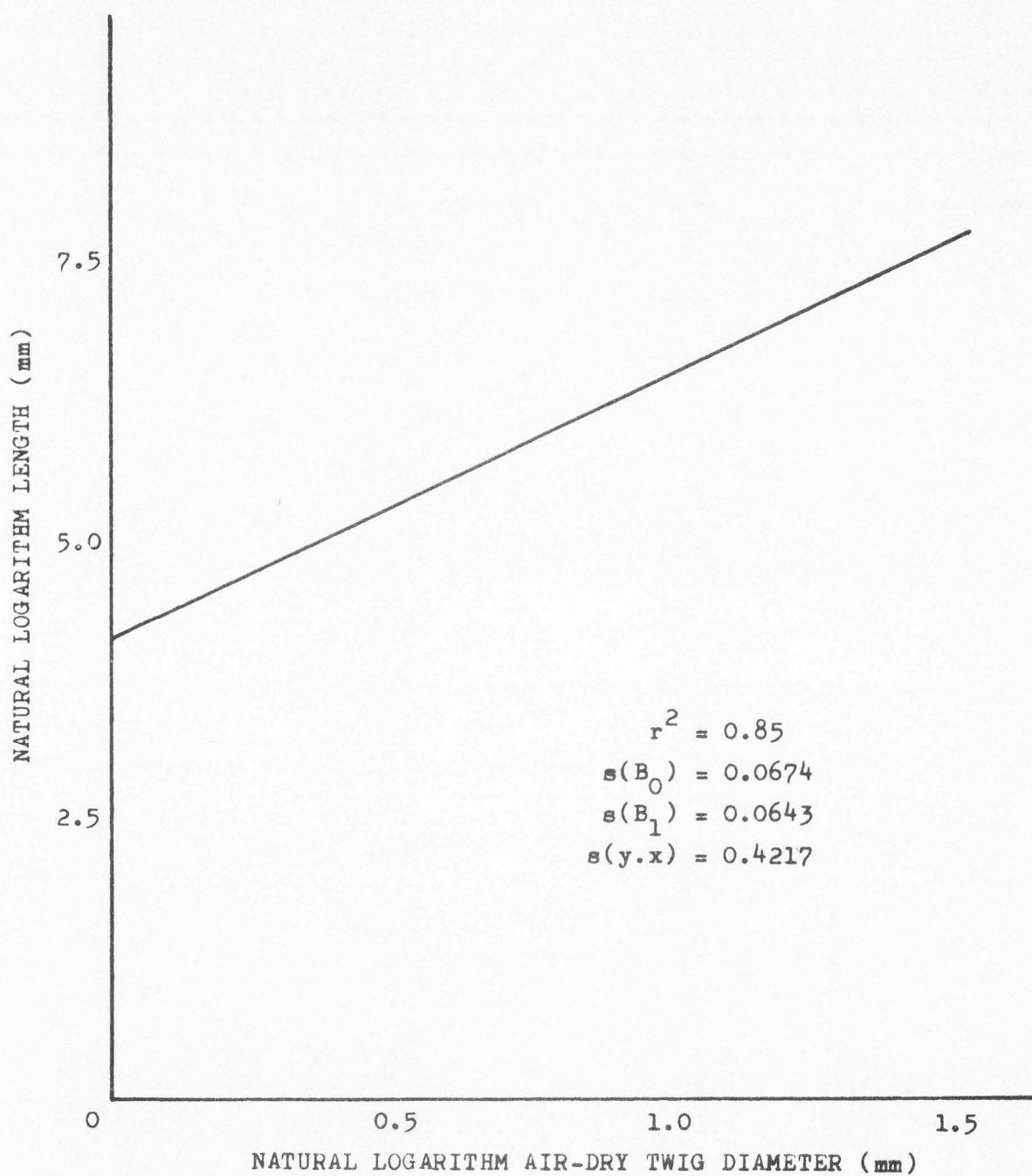


Figure 9. Relationship of twig length to air-dry twig diameter for blackbrush shrubs in all pastures.



Table 4. Analysis of variance for utilization differences based on the regression approach.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	699	881.75		
Stocking rates	2	31,305.23	14.74	P=0.064
Replications	1	4.98	<1	NS
Error	2	2,123.27		
Sampling	694	791.76		

lower probability level than differences based on the before-and-after approach, due to the greater stocking rate x replication mean square which is the error term for the F test.

Percent utilization varied among pastures with the same stocking rates, but the differences were not large. One factor influencing percent utilization was the volume of blackbrush in each pasture. If the volume of blackbrush between paired pastures was similar, utilization rates should have been similar, assuming goats consumed the same amount of blackbrush in each pasture. The volume of blackbrush in each pasture, computed by multiplying the number of plants by the average volume of a plant was: 1H - 3,838 m<sup>3</sup>; 2H - 2,663 m<sup>3</sup>; 1M - 7,938 m<sup>3</sup>; 2M - 4,909 m<sup>3</sup>; 1L - 13,552 m<sup>3</sup>; 2L - 15,561 m<sup>3</sup>. These differences in quantity between paired pastures would lead one to expect considerable variation in percent utilization estimates. It appears, however, that goats did not consume the same amount of blackbrush in each pasture.



### Determining weight removed

Blackbrush density and volume were inversely related ( $r = -0.95$ ); as blackbrush density decreased, mean volume and mean area occupied by individual blackbrush plants increased (Table 5). The density of blackbrush varied between

Table 5. Density, mean area, and volume of blackbrush plants in six pastures.

Pasture <sup>1</sup>	Blackbrush plants per 100 m <sup>2</sup>	Mean area occupied by individual blackbrush plants (m <sup>2</sup> )	Mean volume of individual blackbrush plants (m <sup>3</sup> )
1H	99	1.01	0.40
2H	135	0.74	0.21
1M	115	0.87	0.35
2M	145	0.69	0.18
1L	102	0.98	0.34
2L	118	0.85	0.34

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

replications ( $P=0.057$ ). The mean density for replication one was 106 plants per 100 m<sup>2</sup>, while the mean density for replication two was 128 plants per 100 m<sup>2</sup>. The mean volume of individual blackbrush plants also varied between replications (Figures 10 and 11).

To improve density estimates for determining the number of plants per pasture, samples from pastures with similar plant densities, mean areas, and volumes were pooled. This increased sample size, which increased degrees of freedom and reduced confidence limits on the estimated weight of blackbrush removed



Figure 10. View of a blackbrush plant in pasture 2H.

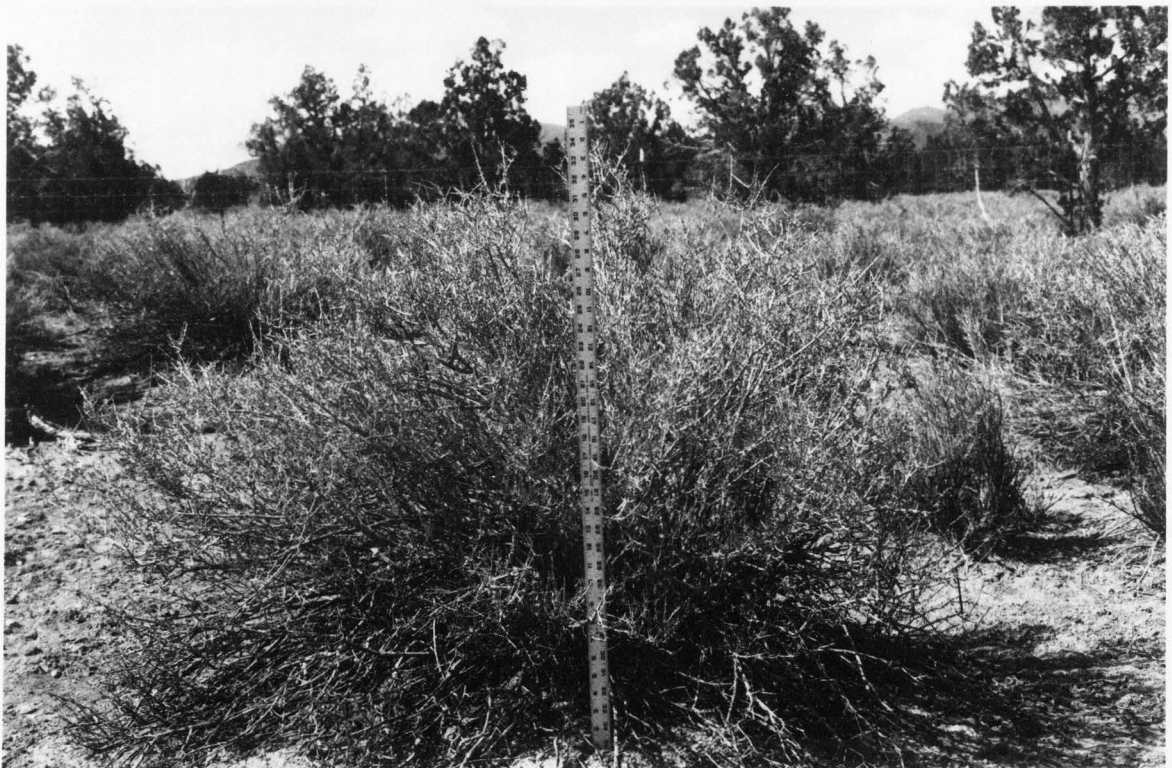


Figure 11. View of a blackbrush plant in pasture 1H.

from each pasture. Sample densities for pastures 1H and 1L, 1M and 2L, and 2H and 2M were pooled for use in estimating the number of plants per pasture. Pasture area estimates were adjusted for areas cleared of blackbrush for fence construction.

An important step in quantifying kilograms of blackbrush browsed by goats was converting browsed branch diameter to browsed twig weight. Figure 12 presents regression lines relating oven-dry twig weight to air-dry twig diameter for each pasture, and Table 6 presents the estimated regression coefficients and F ratios for each pasture.

The intercept for pasture 1L and the slope for pasture 1H were statistically significant additions to the model; however, these additions were not considered practically important due to the small magnitudes of the estimated regression coefficients (1L = 0.244, 1H = 0.299). The best estimate of the regression parameters was obtained by pooling the data from all pastures. Figure 13 presents the regression line, and the regression equation is:

$$\text{natural logarithm weight} = -3.2072 + 3.3789(\text{natural logarithm diameter})$$

Table 7 summarizes data used to compute estimates of the kilograms of blackbrush browsed per hectare by goats in each pasture. Utilization levels of 1164, 582, and 291 kg per hectare were projected (77, 38, and 19 percent) for the heavily, moderately, and lightly stocked pastures, respectively. These data support the findings of the before-and-after and regression approaches which indicate low utilization levels.

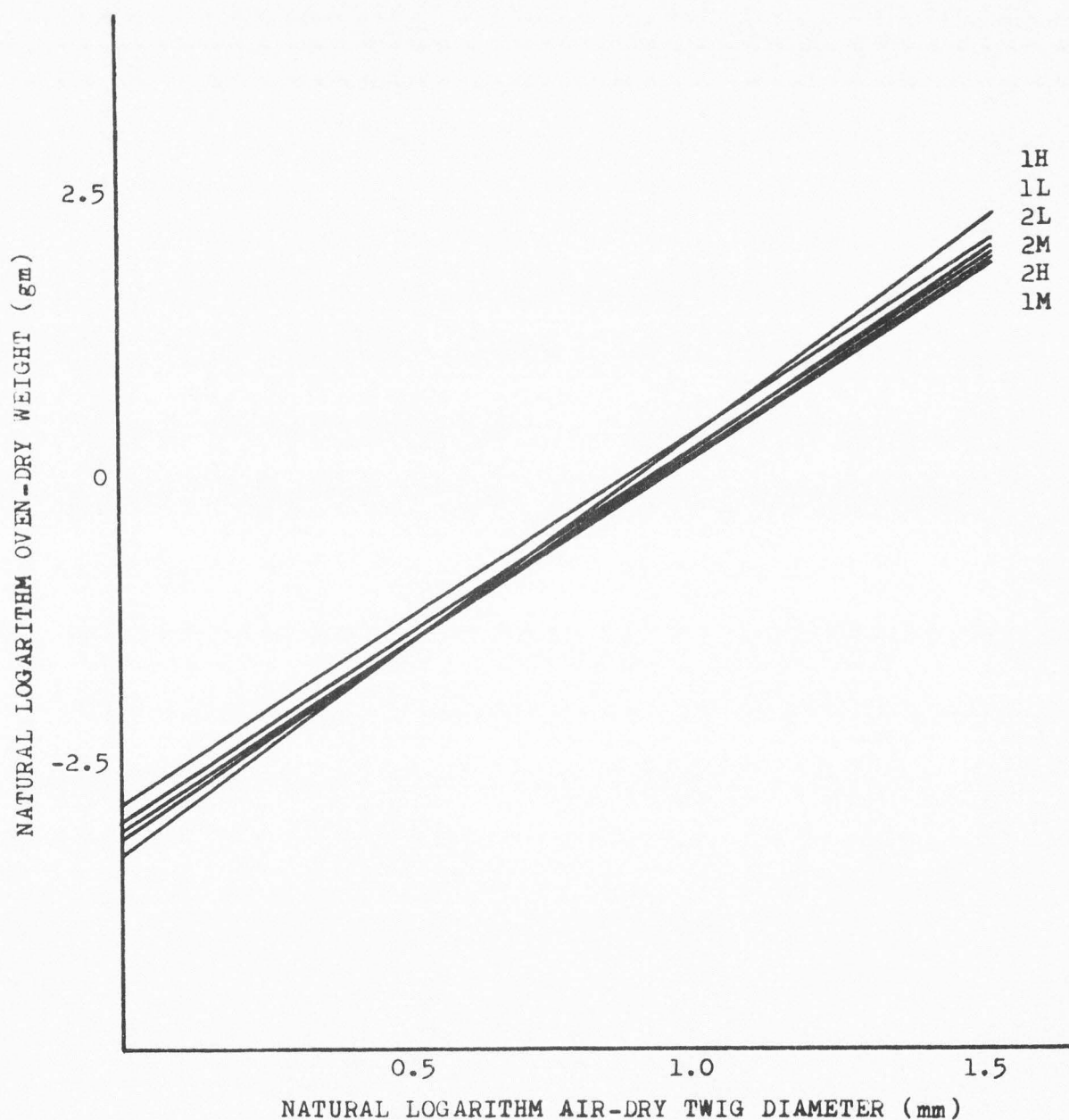


Figure 12. Relationship of oven-dry twig weight to air-dry twig diameter for blackbrush shrubs in six pastures.



Table 6. Estimated regression coefficients for six pastures in which oven-dry twig weight was regressed on air-dry twig diameter.

Pasture <sup>1</sup>	Regression coefficient	Estimated regression coefficient	F ratio	Significance
2L	B <sub>0</sub>	-3.225		
2L	B <sub>1</sub>	3.393	3381.37	P<0.000
1H	B <sub>2</sub>	-0.180	1.56	NS
1M	B <sub>3</sub>	0.041	0.08	NS
1L	B <sub>4</sub>	0.244	3.19	P=0.076
2H	B <sub>5</sub>	0.053	0.18	NS
2M	B <sub>6</sub>	0.120	0.80	NS
1H	B <sub>7</sub>	0.299	5.04	P=0.026
1M	B <sub>8</sub>	-0.117	0.74	NS
1L	B <sub>9</sub>	-0.115	0.83	NS
2H	B <sub>10</sub>	-0.105	0.79	NS
2M	B <sub>11</sub>	-0.104	0.70	NS

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.



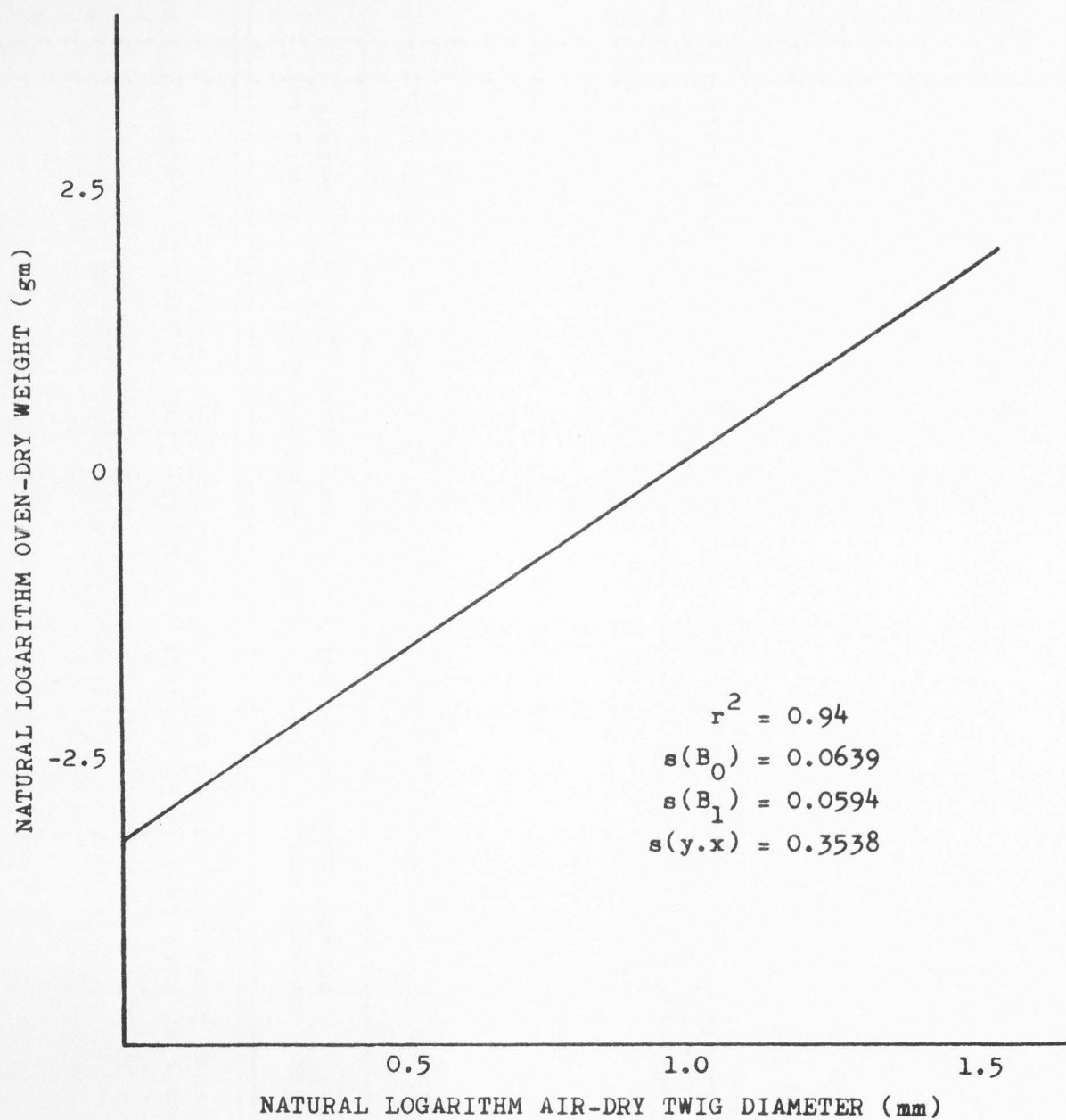


Figure 13. Relationship of oven-dry twig weight to air-dry twig diameter for blackbrush shrubs in all pastures.

Table 7. A summary of data (mean  $\pm$  95 percent confidence limits) used to compute kilograms of blackbrush browsed by Angora goats at three stocking rates.

Pasture <sup>1</sup>	Stocking rate <sup>2</sup>	Browsed twig weight (gm)	Browsed twigs number per plant	Browse removed per plant (gm)	Plants per pasture	Browse removed per hectare (kg)
1H	649	0.57 $\pm$ 0.06	102 $\pm$ 31	58.75 $\pm$ 17.86	9,627 $\pm$ 1,514	566 $\pm$ 192
2H	649	0.70 $\pm$ 0.09	60 $\pm$ 22	41.90 $\pm$ 15.29	12,530 $\pm$ 1,329	524 $\pm$ 199
1M	325	0.51 $\pm$ 0.04	54 $\pm$ 15	27.51 $\pm$ 7.37	22,778 $\pm$ 1,973	313 $\pm$ 89
2M	325	0.70 $\pm$ 0.07	44 $\pm$ 18	30.98 $\pm$ 12.76	27,094 $\pm$ 2,874	420 $\pm$ 181
1L	162	0.49 $\pm$ 0.04	37 $\pm$ 14	18.44 $\pm$ 6.73	39,374 $\pm$ 6,193	182 $\pm$ 75
2L	162	0.47 $\pm$ 0.05	21 $\pm$ 7	9.87 $\pm$ 3.38	45,486 $\pm$ 3,939	112 $\pm$ 41

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

<sup>2</sup>Goat days per hectare

Confidence limits around the weight estimates are broad due to the number of parameters involved in the calculations and the variability associated with each parameter. These estimates, however, provide an indication of the amount of blackbrush removed by goats at the three stocking rates.

Factors possibly contributing to variability in all three methods of determining utilization of blackbrush include an unrepresentative sample in one or more of the pastures, and goat use of alternate forages, such as desert peach (Prunus fasciculata), which was not present in all pastures.

Table 8 presents mean goat weights at the beginning of

Table 8. Body weight and calculated blackbrush consumption data (mean  $\pm$  95 percent confidence limits) for Angora goats browsing pastures at three stocking rates.

Pasture <sup>1</sup>	Stocking rate <sup>2</sup>	Body weight (kg)	Blackbrush consumed per goat per day (kg)	Percent of body weight consumed (kg)
1H	649	30.0 $\pm$ 5.1	0.87 $\pm$ 0.30	0.03 $\pm$ 0.01
2H	649	29.2 $\pm$ 4.2	0.81 $\pm$ 0.31	0.03 $\pm$ 0.01
1M	325	31.3 $\pm$ 5.2	0.97 $\pm$ 0.28	0.03 $\pm$ 0.01
2M	325	26.7 $\pm$ 3.1	1.29 $\pm$ 0.56	0.05 $\pm$ 0.02
1L	162	28.1 $\pm$ 5.0	1.12 $\pm$ 0.46	0.04 $\pm$ 0.02
2L	162	29.0 $\pm$ 7.3	0.69 $\pm$ 0.25	0.02 $\pm$ 0.01

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

<sup>2</sup>Goat days per hectare

the browsing period, the mean amount of blackbrush consumed per goat each day, and the mean percent of body weight consumed

per goat each day. Consumption levels, calculated on the basis of daily forage disappearance from the experimental pastures, were not much different than those recorded by Huston et al. (1971) for pregnant Angora does fed varying levels of ground sorghum hay, cottonseed meal, and ground oats. Due to the imprecision of the method used to determine blackbrush consumption levels, however, these values provide only an indication of the kilograms of blackbrush consumed per goat each day.

Table 9 presents the analysis of variance for the grams of

Table 9. Analysis of variance for utilization differences based on grams of blackbrush removed from plants.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	699	2,279.7		
Stocking rates	2	56,769.7	14.04	P=0.066
Replications	1	6,898.1	1.71	NS
Error	2	4,042.0		
Sampling	694	2,110.8		

blackbrush removed from plants at the three stocking rates. This analysis indicates significant differences in the weight of forage removed from plants at the three stocking rates. The results of this analysis correspond to the results of the analyses for the before-and-after and regression approaches.

Man-hour costs can be greatly reduced if predicted utilization (regression approach) or observed utilization (before-and-after approach) is used to estimate the kilograms of blackbrush browsed by goats. A strong relationship exists

between utilization in kilograms per hectare and predicted utilization, and utilization in kilograms per hectare and observed utilization. Table 10 presents a summary of

Table 10. Regression parameters obtained from regressing utilization in kilograms per hectare on predicted utilization (1), and kilograms per hectare on observed utilization (2).

Regression line	Regression coefficient	Estimated coefficient and standard error	s(y.x)	r <sup>2</sup>
1	B <sub>0</sub>	74.6575, 31.9068	39.7360	0.96
	B <sub>1</sub>	14.7310, 1.4541		
2	B <sub>0</sub>	70.8873, 32.4273	39.9748	0.96
	B <sub>1</sub>	16.1500, 1.6041		

parameters for the regression of kilograms of blackbrush browsed on predicted utilization, and kilograms of blackbrush browsed on observed utilization.

If results of predicted or observed utilization are available, kilograms of blackbrush browsed by goats can be determined without time-consuming counts and caliper measurements of twigs. The greatest time savings results if the regression approach is used to predict percent utilization, and percent utilization is then converted to kilograms of blackbrush browsed.

The primary weakness in using percent utilization to predict kilograms of blackbrush removed is the limited range of data. Only utilization values from 4 to 34 percent can be used to predict kilograms of blackbrush browsed, because there are no data outside this range. Thus, at heavier stocking rates



anticipated in future research, new regression equations will have to be developed to cover heavier utilization levels.

### Quantifying Body Weight Response

Knowledge of the body weight response of goats browsing blackbrush is basic for guiding management decisions and future research. Does that gave birth during the study lost an average of 26 percent of body weight, does that did not give birth lost an average of 16 percent of body weight, and male and female yearlings lost an average of 16 percent of body weight. The analysis of variance for weight loss is presented in Table 11. Does that gave birth during the study were deleted

Table 11. Analysis of variance for Angora goat weight loss.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	50	21.38		
Stocking rates	2	8.44	<1	NS
Replications	1	373.69	17.63	P=0.052
Error	2	21.19		
Sampling	45	14.02		

from the analysis because not all pastures contained equal numbers of lactating females. This necessitated a least squares regression solution to the analysis of variance.

Due to the low stocking rates even under the "heavy" regime, forage was not limiting in any of the pastures. Hence, goats at the three stocking rates showed no trend in weight loss. There

were, however, significant differences in percent weight loss between replications. Goats lost an average of 14 and 19 percent of body weight in replications one and two, respectively. Figure 14 is a graph of the pasture means. Differential weight loss appears to be related to nutrient content differences in blackbrush plants in the two replications.

#### Quantifying Crude Protein and Phosphorus Content

Hand-plucked blackbrush samples, that duplicated material consumed by goats, were collected from each pasture seven times during the browsing period and analyzed for crude protein and phosphorus content (Table 12). Table 13 presents the analysis

Table 12. Crude protein and phosphorus content (dry-matter basis) of blackbrush twigs collected at seven dates during the browsing period.

Pasture <sup>1</sup>	Percent crude protein	Percent phosphorus
1H	5.1	0.19
1M	4.7	0.16
1L	4.8	0.18
2H	4.3	0.15
2M	4.2	0.15
2L	4.6	0.14
Means:		
Replication 1	4.9	0.18
Replication 2	4.4	0.15
Overall	4.6	0.16

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

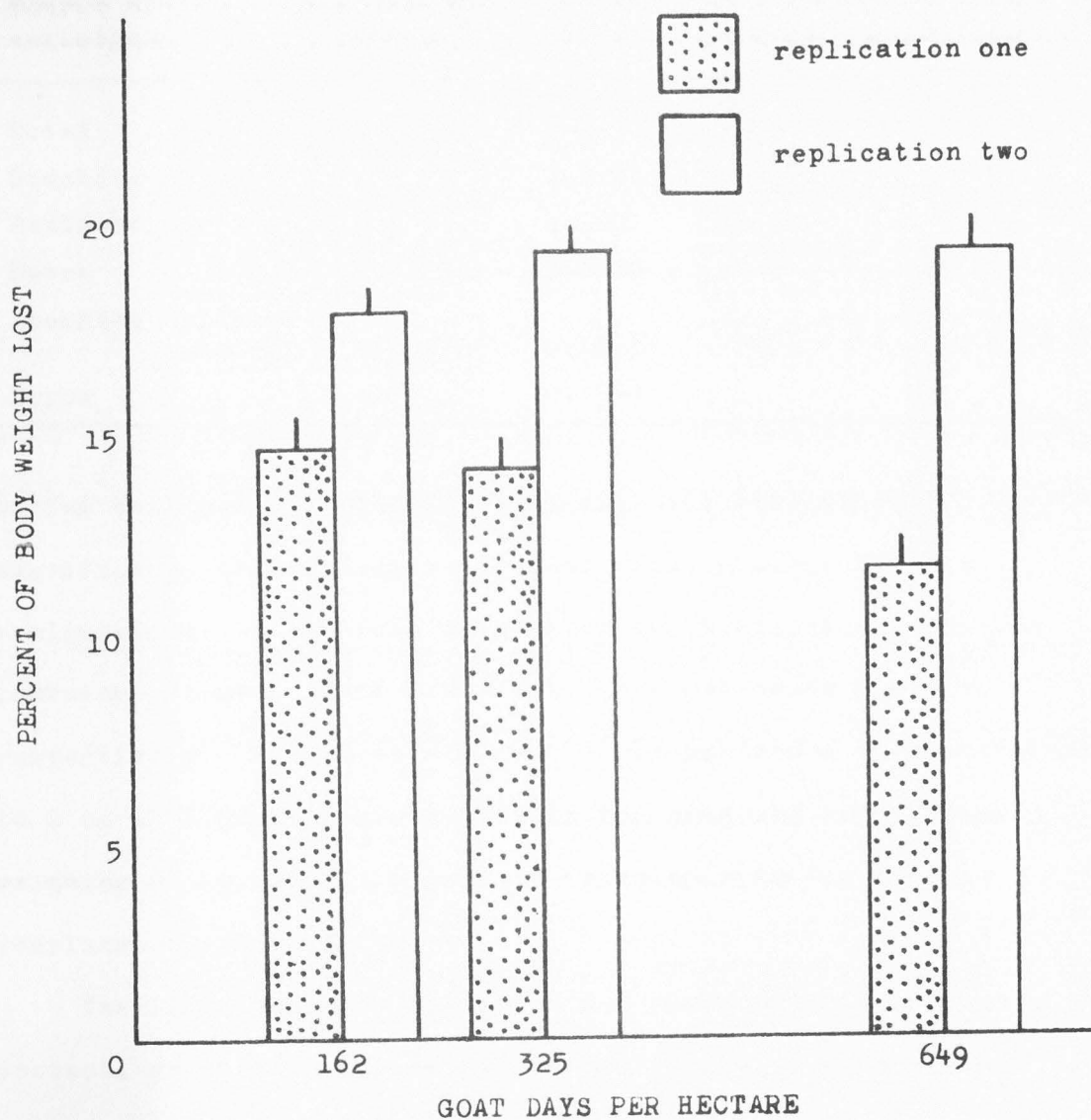


Figure 14. Percent of body weight lost by Angora goats browsing pastures at three stocking rates; lines extending above the bars represent half a standard error.

of variance for percent crude protein levels in twigs collected

Table 13. Analysis of variance for percent crude protein content of twigs collected during the browsing period.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	41	0.2226		
Stocking rates	2	0.2266	1.17	NS
Replications	1	2.5901	13.32	P=0.002
Dates	6	0.1520	<1	NS
Stocking rates x dates	12	0.1068	<1	NS
Error	20	0.1944		

during this period. There were small, but statistically significant, differences in percent crude protein between replications. Blackbrush twigs from replications one and two contained an average of 4.9 and 4.4 percent crude protein, respectively. Huston et al. (1971) recommended a diet containing 10.0 to 10.5 percent crude protein for pregnant Angora does weighing 27 kg, and 11.6 percent crude protein for Angora yearlings weighing 18 kg.

The individual pasture means for percent crude protein content, graphed in Figure 15, ranged from 4.2 percent for pasture 2M to 5.1 percent for pasture 1H. This corresponded with a range of 19.5 to 11.6 percent of body weight lost by goats browsing pastures 2M and 1H, respectively. Figure 16 is a graph of the regression line relating percent of body weight lost to percent crude protein in the diet. The data suggest

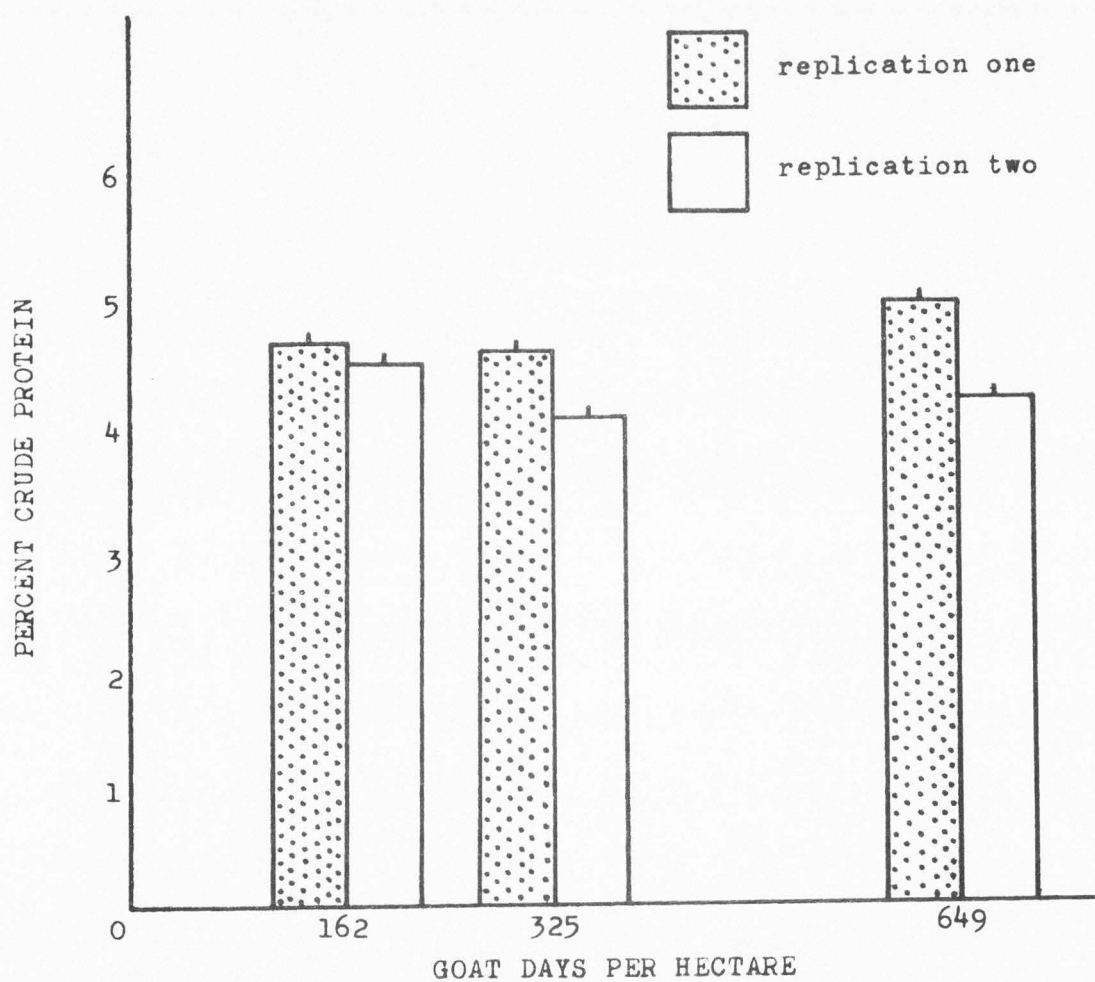


Figure 15. Percent crude protein content for blackbrush twigs in pastures browsed by Angora goats; lines extending above the bars represent half a standard error.



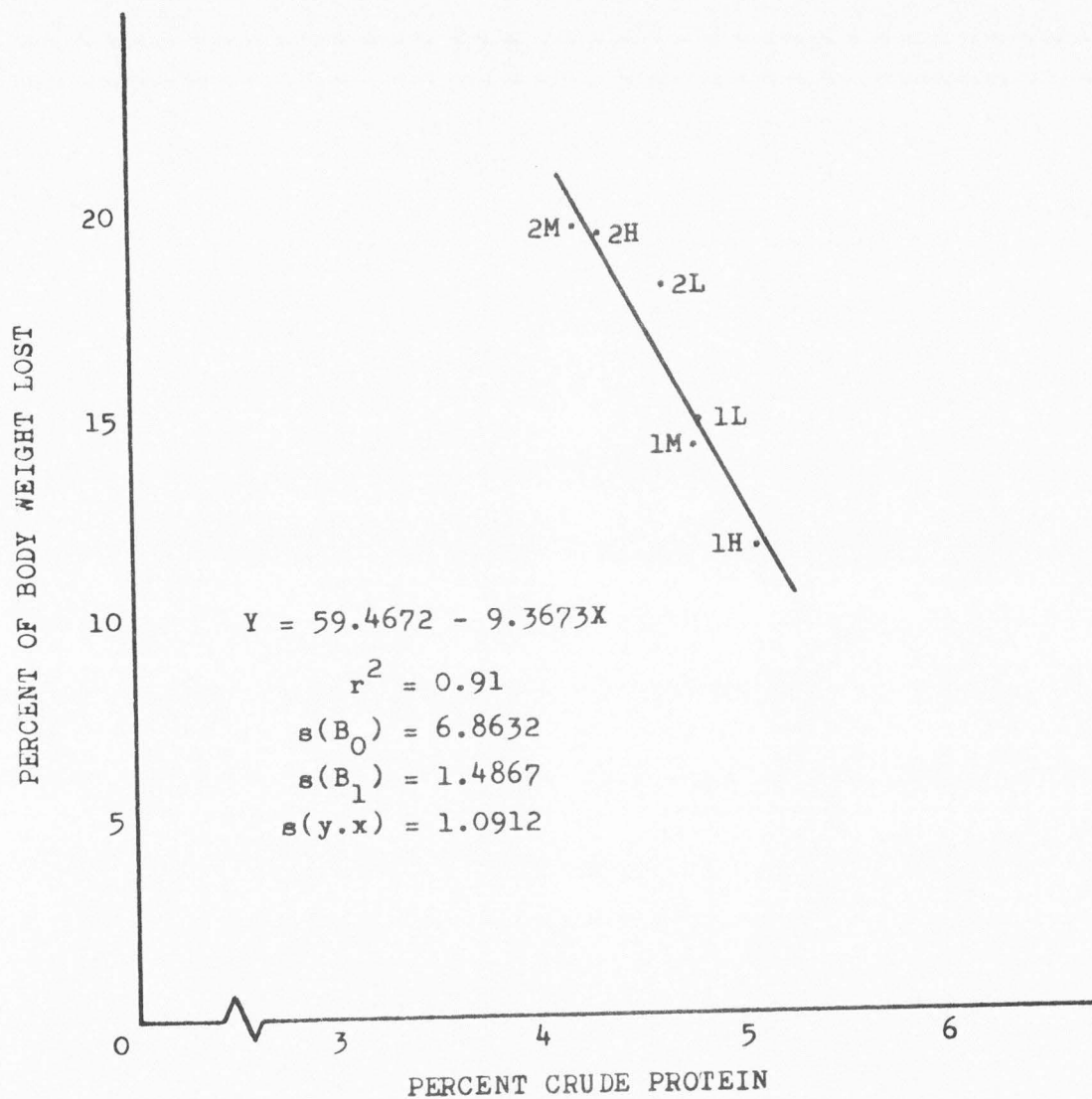


Figure 16. Relationship between percent of body weight lost by Angora goats and percent crude protein content of blackbrush twigs in the goats' diet.

crude protein content differences among pastures, and that goat weight loss is related to these differences.

Moir and Harris (1962) fed sheep a ration in which the nitrogen content was varied progressively from 0.32 to 1.50 percent (2.0 to 9.4 percent crude protein). Dry-matter intake and intake rate were both reduced as nitrogen intake decreased below 0.74 percent (4.6 percent crude protein). Digestibility of dry-matter and crude fiber decreased when nitrogen intake was reduced below 0.87 percent (5.5 percent crude protein). Cellulose digestion, measured by the rate of disappearance of cotton thread placed in the rumen, decreased as nitrogen intake decreased below 0.84 percent (5.3 percent crude protein). A strong positive relationship was shown between nitrogen intake and the rate of cellulose digestion (cotton thread) in the rumen. The concentration of ruminal bacteria was shown to be highly, positively correlated with nitrogen intake; more than a tenfold decrease in rumen bacteria occurred over the decreasing range of nitrogen fed. These changes in bacterial concentrations were significantly correlated with cellulose (cotton thread) digestion. Angora goats browsing in pastures with higher blackbrush nitrogen content were probably better able to digest the high fiber blackbrush diet; as a result, goats on diets higher in nitrogen lost less weight.

Because harvested blackbrush material was lacking for certain pastures, phosphorus determinations could not be made for all pastures at all collection dates. This necessitated a least squares regression solution to the analysis of variance

(Table 14). Phosphorus content varied between replications;

Table 14. Analysis of variance for percent phosphorus content of twigs collected during the browsing period.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	35	0.000732		
Stocking rates	2	0.001029	2.23	NS
Replications	1	0.003203	6.96	P=0.019
Dates	6	0.000812	1.76	NS
Stocking rates x dates	12	0.000540	1.17	NS
Error	14	0.000460		

blackbrush twigs from replications one and two contained an average of 0.18 and 0.15 percent phosphorus, respectively. Huston et al. (1971) recommended a diet containing 0.17 percent phosphorus for pregnant Angora does weighing 27 kg, and 0.18 percent phosphorus for Angora yearlings weighing 18 kg.

Bowns and West (1976) indicated that blackbrush was deficient in phosphorus. Wallace and Romney (1972), however, found the phosphorus content of blackbrush to range from 0.06 to 0.20 percent for stems and 0.07 to 0.28 percent for leaves, depending on soils and location. Data from this study support the hypothesis that phosphorus content of blackbrush is adequate for meeting recommended requirements (Cook and Harris 1968, Huston et al. 1971) of certain sex, age, and physiological livestock classes if environmental factors are favorable for blackbrush plants.

Available soil moisture, temperature, soil type, site, and general climatic conditions have all been shown to influence the chemical composition of plants. The effects of soil variables on plant nutritive content are difficult to evaluate, however, because of interdependent factors including soil acidity, soil moisture, structure, texture, organic-matter content, soil organisms, and chemical composition of the soil solution (Cook and Harris 1950). Daniel and Harper (1934) concluded that the study of a single nutrient element in the soil did not give a reliable indication of the amount of that element in the plant since many soil factors were involved and plant species varied in their ability to utilize soil nutrients. Cook and Harris (1950) concluded that environmental factors and soil moisture were more important in determining the nutrient content of range plants under various site conditions (slope, exposure, vegetation cover) than the chemical content of the soil. Nevertheless, Stoddart (1941) found that snowberry (Symphoricarpos rotundifolius) plants grown on various soil types showed marked differences in ash, protein, and phosphorus content, and Midgley (1937) indicated that soils with high mineral content produced plants high in minerals. Stoddart et al. (1975) concluded from a review of the literature that good sites and good growing conditions produced good forage.

Because crude protein and phosphorus content differences between replications were not anticipated, only a qualitative statement can be made about possible factors influencing crude protein and phosphorus levels in blackbrush at the study site.

The obvious differences in pastures at the study site were topographical. Pastures 2H and 2M included larger areas of relatively steep slopes than pastures 1H, 1M, 1L, and 2L, and soils in replication two contained more surface stone than soils in replication one. Bowns (1973) indicated that the petrocalcic layer was 46 cm below the soil surface. In digging seventy-two 122-cm post holes on the study site, I encountered soil depth differences in the A-C horizon. In replication one, depth of soil to the petrocalcic layer was greater than 46 cm on average; and in replication two, soil depth to the petrocalcic layer was equal to or less than 46 cm on average. Shreve and Mallery (1953) considered the petrocalcic horizon a definite obstacle to blackbrush roots, and Bowns (1973) indicated that blackbrush roots penetrated this horizon only where it had been fractured.

Perhaps greater soil depth permitted better soil moisture relations for plants in replication one. Also, with greater soil depth, plants in replication one may have been able to obtain more soil nutrients. Harner and Harper (1973) stated that improved soil moisture relations probably enhance the mineral status of soils through accelerated microbial action which causes the release of essential elements; their data showed that soil moisture and the nutrient content of vegetation were closely related. Bhaumik and Clark (1947) indicated that decomposer organisms of the soil performed optimally at moisture levels near field capacity if aeration and temperature were favorable; Moser and Olson (1953) indicated that as a soil dries the



activity of soil organisms declines rapidly.

### Quantifying Plant Response

No statistically significant differences in production of current season's growth were noted among stocking rates, and differences between replications and branch locations were not highly significant (Table 15). Nevertheless, production

Table 15. Analysis of variance for blackbrush twig production in response to Angora goat browsing.

Source of variation	Degrees of freedom	Mean square	F ratio	Significance
Total	1599	26,066		
Stocking rates	3	733,310	1.73	P=0.332
Replications	1	1,445,763	3.40	P=0.162
Error A	3	424,705		
Locations	1	981,383	3.50	P=0.135
Locations x stocking rates	3	256,980	<1	NS
Error B	4	280,531		

trends were apparent for the heavy stocking rate, between replications, and between branch locations.

Plants in replication one produced an average of 132 mm of current season's growth per branch while plants in replication two produced an average of 62 mm of current season's growth per branch (Figure 17). Plants in the heavily stocked pastures produced an average of 180 mm of current season's growth per branch while control pastures produced an average of 74 mm of current season's growth per branch. However, plant response at

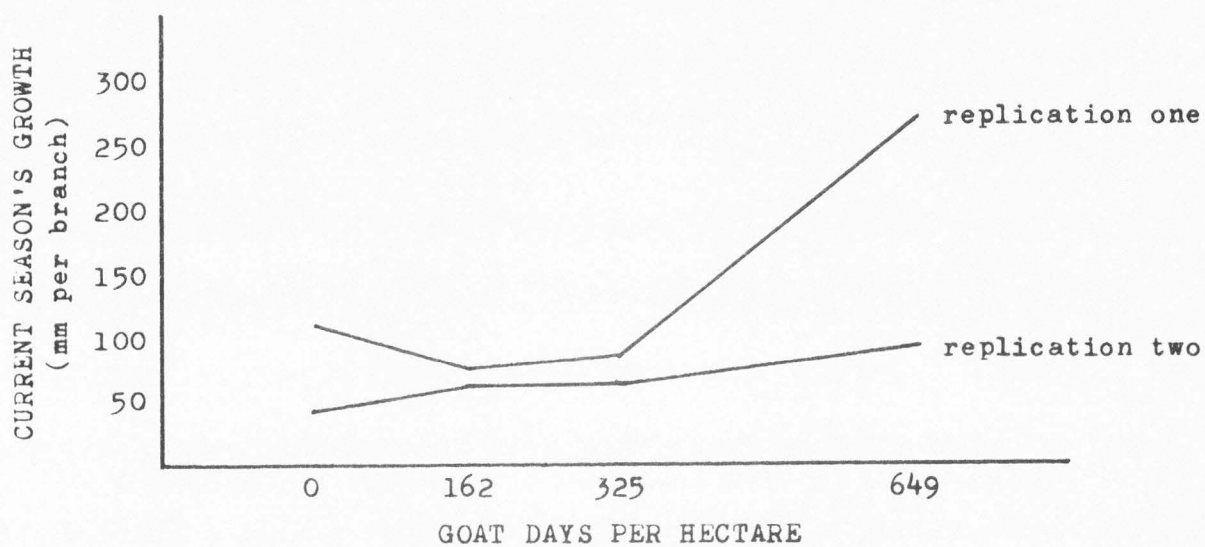


Figure 17. Current season's growth produced by blackbrush branches in pastures at four stocking rates.

the heavy stocking rate appeared to be affected by soil depth and soil stoniness. Plants in 1H produced an average of 273 mm of current season's growth per branch while plants in 2H produced an average of 87 mm of current season's growth per branch (Figure 17). Plants in 2H did not greatly outproduce plants in the control pasture for replication two, which produced an average of 43 mm of current season's growth per branch.

Medin (1960) studied the influence of 12 physical site factors on the annual production of mountain mahogany (Cercocarpus montanus). Soil depth was the most important factor influencing plant production. From 34 to 114 kg of current season's growth per 0.4 hectare were produced on soils that ranged in depth from 3 to 20 cm, respectively. As soil depth increased above 20 cm, however, plant production increased at a decreasing rate. Soil surface stoniness was inversely related to production in mountain mahogany; least productive plants were on sites with stony soil surfaces. Medin (1960) concluded that factors influencing soil moisture relations were key factors influencing production in mountain mahogany, and that as soil depth increased more water was stored for use by plants. Black (1968) indicated that soil depth was related to plant production through association with the primary factors of water, oxygen, and nutrients. On the average, pastures in replication two had shallower soils with more surface stone than did pastures in replication one.

Terminal branches consistently produced more current season's growth than did basal branches (Figure 18). Terminal branches in

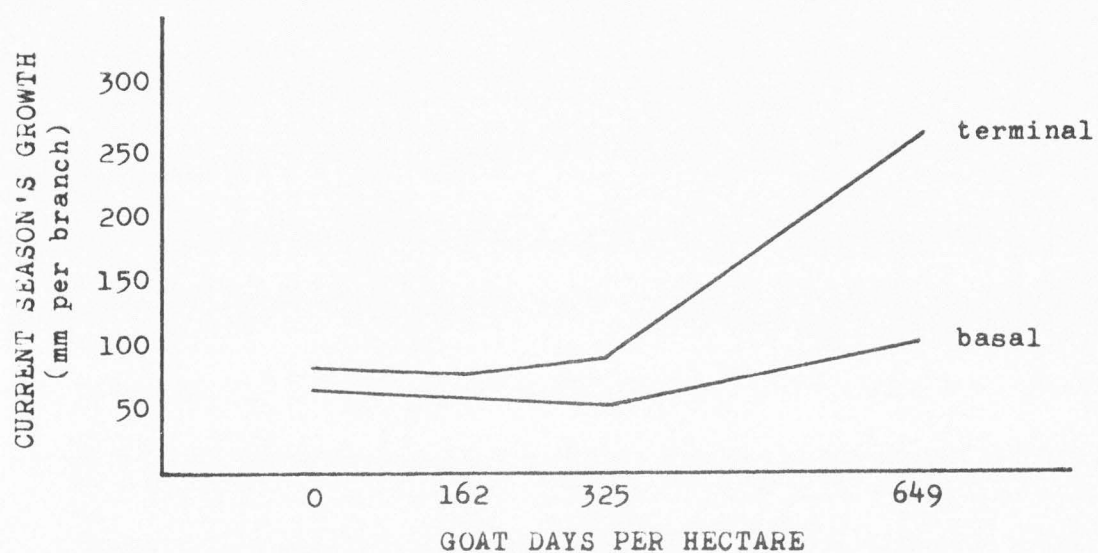


Figure 18. Current season's growth produced by terminal and basal branches at four stocking rates.

the heavily stocked pastures produced an average of 258 mm of current season's growth while basal branches in heavily stocked pastures produced an average of 102 mm of current season's growth. Basal branches are younger than terminal branches and are located within the spinescent canopy of terminal branches. As a result, they are not readily available to browsing ungulates. Current season's growth on terminal branches, however, is readily available to browsing ungulates (Figure 19).

The data indicate that only in the one hectare pastures were stocking rates adequate to produce plant response. However, even at the "heavy" stocking rate, utilization levels and subsequent plant response were low. If the projected utilization levels of 77, 38, and 19 percent had been realized in the heavily, moderately, and lightly stocked pastures, respectively, plant response would have greatly increased.

Great plant-to-plant variation in production of current season's growth occurred as a result of selective browsing by goats. The relationship between the weight of twig material removed from individual sample plants and the subsequent growing season's twig production was not strong for any pasture, but was weakest for the moderately and lightly browsed pastures (Table 16). This was primarily a result of the low utilization levels, but the sampling procedure used to determine production of current season's growth also contributed to variability in the relationships. In general, only browsed branches responded with large increases in current season's production; the chances





Figure 19. Current season's growth on a terminal branch of a blackbrush plant.

Table 16. Correlation coefficients for the relationship between weight of browse removed by Angora goats and current season's twig production by blackbrush (means  $\pm$  95 percent confidence limits).

Pasture <sup>1</sup>	Stocking rate <sup>2</sup>	Browse removed per plant (gm)	Current season's growth (mm)	Correlation coefficient
1H	649	59 $\pm$ 18	273 $\pm$ 30	0.57
2H	649	42 $\pm$ 15	87 $\pm$ 30	0.56
1M	325	28 $\pm$ 7	79 $\pm$ 21	0.40
2M	325	31 $\pm$ 13	59 $\pm$ 21	0.14
1L	162	18 $\pm$ 7	73 $\pm$ 15	0.45
2L	162	10 $\pm$ 3	60 $\pm$ 15	0.27
<hr/>				
Replication 1		36 $\pm$ 5	132 $\pm$ 12	0.52
Replication 2		15 $\pm$ 5	62 $\pm$ 12	0.27

<sup>1</sup>H, M, and L designate heavy, moderate, and light stocking intensities, respectively. Numbers denote replicates.

<sup>2</sup>Goat days per hectare

of selecting a browsed branch for measurement of current season's growth on moderately and lightly browsed plants was relatively low. Hence, sample plants that had moderate amounts of forage removed may have showed little current season's growth if an unbrowsed twig was selected for the production measurement. Also, hare (Lepus californicus) use of some sample plants contributed to variability in the relationship between goat utilization and plant response since hare-browsed sample plants generally showed large production of current season's growth, but had no forage removed by goats.

## CONCLUSIONS AND RECOMMENDATIONS

Blackbrush occurs on millions of hectares of rangeland in the southwestern United States. The shrub is generally considered a poor forage species; its compacted, spinescent growth form makes accessibility and palatability of twigs low for many ungulates. Angora goats were used to remove spinescent twigs from blackbrush with the objective of stimulating production of current season's growth which is generally more available and more palatable to ungulates than are the spinescent twigs.

Specific objectives of this study were to determine the effects of three levels of goat browsing on blackbrush utilization, to quantify the body weight response of goats browsing blackbrush, to determine the crude protein and phosphorus content of blackbrush during the browsing period, and to assess the relationship between utilization levels and the subsequent growing season's production of blackbrush twigs. The results of this research support the following conclusions:

1. Statistically significant differences were noted for utilization levels of 649, 325, and 162 goat days per hectare, but only utilization levels of 649 goat days per hectare showed trends toward increased production of current season's growth.
2. Percent utilization of blackbrush twigs was accurately determined using a regression method to relate browsed twig diameter to twig length.

3. Angora goats lost 16 percent of their body weight while browsing blackbrush. Weight loss varied among pastures and was apparently related to variable crude protein levels in blackbrush plants in the pastures.

4. Crude protein content averaged 4.6 percent and phosphorus content averaged 0.16 percent for all pastures during the winter browsing period.

5. No statistically significant increases in plant production were noted among stocking rates. This was primarily a result of the low utilization levels since plants in heavily browsed pastures produced 2.4 times more current season's growth than control pastures.

6. Site affected plant growth response. Heavily browsed plants growing in deep soils with little surface stone produced 3.1 times more current season's growth than did heavily browsed plants growing in shallow soils with much surface stone.

7. Terminal branches produced 2.5 times more current season's growth than did basal branches in the heavily stocked pastures. Growth on terminal branches is probably more available to browsing cattle than is growth on basal branches.

Goats removed spinescent blackbrush twigs which stimulated production of twigs that are probably more available and more palatable for cattle consumption; however, stocking rates of at least 649 goat days per hectare are necessary for substantially increasing plant production of new twigs. The following are recommendations for future research:

1. Increase the heavy, moderate, and light stocking rates



to 1200, 600, and 300 goat days per hectare (20 goats for 60 days on all pastures), respectively. These stocking rates should provide desired utilization levels if supplemented Angora wethers, which are larger than Angora does and yearlings, are used.

2. Provide goats with a protein-phosphorus supplement; also, goats might need an energy supplement. Many shrubs are low in energy during winter (Cook 1972) and blackbrush appears to be one of them. Huston et al. (1971) obtained weight losses of 16 percent in Angora goats only by feeding diets deficient in both energy and protein. If either energy or protein were adequate in the diet, goats lost no weight.

3. Use a split plot design for supplementing goats in each pasture by dividing goats into four groups (5 goats per group) and feeding each group a different level of supplement (the same levels in all pastures). Each pasture should contain a control group of goats that receive no supplement. Split plot supplementation will provide data for determining the best level of supplementation for the least cost.

4. The body weight response of goats should be determined by weighing goats at two-week intervals during the browsing period.

5. Crude protein and phosphorus levels in blackbrush twigs consumed by goats during the browsing period should be determined to supplement weight response data, as nutrient levels may have changed in the heavily browsed pastures.

6. Crude protein and phosphorus levels in blackbrush twigs



produced from this year's (1977) goat browsing should be collected during next year's (1978) browsing period and analyzed to determine if levels of these nutrients have increased.

7. Utilization should be quantified using the regression approach.

8. Plant response should be quantified by the same method used this year to separate stocking rate, replication, and location effects.

9. Apply a cattle browsing treatment during the winter of 1979 following recommendations 1,2,3,4,5,6, and 8. Stocking rates for cattle may need to be adjusted (recommendation 3), and utilization may need to be quantified by the before-and-after method (recommendation 7) if plant morphology has changed as a result of goat browsing. Also, cattle should be stocked on control pastures so that utilization and body weight response can be compared between control and treated pastures. Tagged sample plants in control pastures should be protected from cattle browsing with utilization cages.

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## VITA

Frederick D. Provenza

Candidate for the Degree of

Master of Science

Thesis: Biological Manipulation of Blackbrush (Coleogyne ramosissima Torr.) by Browsing with Goats.

Major Field: Range Science

Biographical Information:

Personal Data: Born at Colorado Springs, Colorado, May 14, 1951, son of Stanley P. and Jean L. Provenza; Married Sue Smith September 14, 1974.

Education: Graduated from Salida High School 1969; obtained Bachelor of Science Degree in Wildlife Biology from Colorado State University in 1973.

Professional Experience: Summer employment with Salida Greenhouse from 1966 to 1969; summer ranch employment from 1971 to 1973; winter employment as assistant coach of the Monarch Ski Racing Club 1971 to 1975; ranch manager from 1973 to 1975; carpenters helper summer 1975; research technician for Range Science Department, Utah State University from September 1976 to July 1977.